

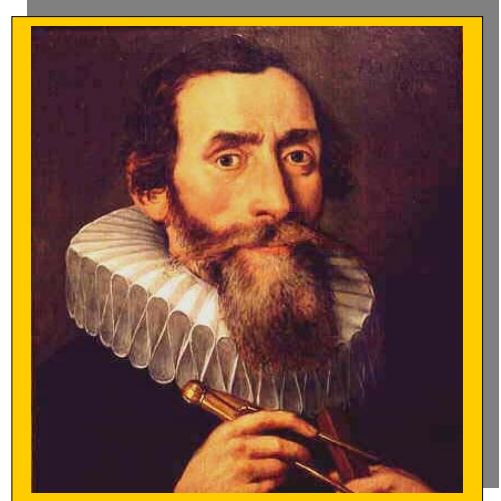
Destination L1: A Thematic Unit

Kepler's Laws of Planetary Motion

TEACHER GUIDE - SCIENCE

BACKGROUND INFORMATION

The science activities in this module deal with the concept of travel as it relates to natural objects (planets) traveling around the sun. The activities are designed to let the students discover Kepler's Laws of Planetary Motion by completing assignments about the laws. In the first activity, "Round and Round," students are given some historical context by reading background information about Nicolaus Copernicus, Tycho Brahe, and Johannes Kepler. Students then construct an ellipse using two different methods. They discover that planets orbit around the sun in elliptical orbits (first law). Using one of these ellipses, students are introduced to the concepts of the focus and the semi-major axis of an ellipse. By applying these concepts, they determine the eccentricity of an ellipse and compare this with the relative roundness of the planetary orbits. In the second activity, "Sweepstakes," students learn that as a planet travels around the sun, at different points it sweeps out equal areas in equal times (second law). In the third activity, "The Inclined Pendulum," students model the fact that a decrease in gravity causes a decrease in orbital velocity using a simulation, and those more distant planets revolve around the sun at slower velocities (third law). Finally, the students conclude by reading the Student Text, "L1 or Bust," where they learn about the Lagrange Points and study the trajectory that is used by the Genesis spacecraft during its trip to orbit L1 and back to Earth.



Johannes Kepler (1546-1630) used Tycho Brahe's data to determine the laws of planetary motion.

The *National Science Education Standards* call for teachers to guide and facilitate learning. The activities in this section allow students to discover how the planets travel around the sun in orbits. As teachers carefully observe their students during these activities, they should decide how and when to guide students based on how they are proceeding in the learning.

NATIONAL SCIENCE STANDARDS ADDRESSED

(Source - *National Science Education Standards*)

Grades 5-8

[Science as Inquiry](#)

Understandings about scientific inquiry

[Physical Science](#)

Motions and forces

[Earth and Space Science](#)

Earth in the solar system

[History and Nature of Science](#)

History of science

Grades 9-12

[Science as Inquiry](#)

Understandings about scientific inquiry

[Physical Science](#)

Motions and forces

[History and Nature of Science](#)

Historical perspectives

(View a full text of the [National Science Education Standards](#).)

NATIONAL MATHEMATICS STANDARDS ADDRESSED

(Source – *Principles and Standards for School Mathematics*)

Grades 6-8[Numbers and Operations](#)

Understand numbers, ways of representing numbers, relationships among numbers and number systems.
Understand meanings of operations and how they relate to one another.
Compute fluently and make reasonable estimates.

[Algebra](#)

Use mathematical models to represent and understand quantitative relationships.

[Geometry](#)

Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships.
Use visualization, spatial reasoning, and geometric modeling to solve problems.

[Problem Solving](#)

Solve problems that arise in mathematics and in other contexts.

[Connections](#)

Recognize and apply mathematics in contexts outside of mathematics.

(View a full text of the [Principles and Standards for School Mathematics](#).)

NATIONAL TECHNOLOGY STANDARDS ADDRESSED

(Source – *National Technology Education Standards*)

K-12[Technology productivity tools](#)

Students use technology tools to enhance learning, increase productivity, and promote creativity.

[Technology problem-solving and decision-making tools](#)

Students employ technology in the development of strategies for solving problems in the real world.

(View a full text of the [National Technology Education Standards](#).)

MATERIALS

For each group of two or three students:

- Butcher paper

“Round and Round”

For each group of two or three students:

For Part One

- Wide-mouth jar lid



- 200 watt light bulb
- Electrical socket
- Lamp
- Student Activity, [“Round and Round”](#)
- Pencil
- Metric ruler
- String

For Part Two

- Six push pins
- 15-centimeter loop of string
- Paper
- 30-centimeter square sheet of styrofoam

For Part Three

- Calculator or [Student Spreadsheet](#)

“Sweepstakes”

For each group of two or three students:

- Student Activity, [“Sweepstakes”](#)
- Computer with Internet connection
- Kepler’s Second Law, [Animation](#)

“The Inclined Pendulum”

For each group of four students:

- Metal ring mounted onto a piece of plywood
- Marble
- Student Activity, [“The Inclined Pendulum”](#)
- Student Text, [“L1 or Bust!”](#)
- Stopwatch or other timing device
- Five textbooks (all about the same size)

Teaching Tip

The styrofoam for “Round and Round” and the plywood for “The Inclined Pendulum” can both be purchased at the local hardware store. The metal rings can be purchased at the local craft store.

PROCEDURE (Part One):**“Round and Round”**

1. Activate prior knowledge about planetary orbits by asking students to define an orbit in their own words. They may draw a picture to help illustrate their definition.
2. Ask students to assemble into groups of three or four. Ask them to share their definitions and drawings. Students should then develop a definition of an orbit. Circulate around the room and observe students and their definitions to gauge their understanding.
3. Ask students to list everything the individuals in the group know about a planet’s orbit. Have students list their group definition and what they know on a large sheet of butcher paper.
4. Display the sheets on the walls of the classroom. Instruct students to inspect the definitions, drawings, and pieces of knowledge. Ask them to list any questions that come to mind about planetary orbits in their notebooks as they walk around the room. Allow enough time for students to read and write questions based on all of the group sheets. Ask students to save these questions so they can refer to them throughout the next few lessons. Encourage students to add new questions to their journals as they arise during the following activities. Also, students may write answers in their journals as they reach an understanding of a concept.



5. Explain to students that they will be completing activities dealing with how the planets travel around the sun in their orbits.
6. Distribute the Student Activity “Round and Round” to students in their small groups. Instruct student groups to read the background information, then proceed to Part One of the activity.
7. Provide the students with the materials they will need for Part One, “Round and Round.” As necessary, review with students how to measure the diameter and radius of a circle.
8. Students may use a piece of string to measure the circumference of the circle. Introduce the method of counting squares for determining the area of a circle. Tell students that are using this method to count the squares if there is half or more of the square within the circle. Circulate around the room assisting groups as needed. Make sure that the entire group is asking a question before responding. For the description of the traced object, make sure students write detailed observations. Ask them to describe the shape of the object.
9. You may want to check the groups’ responses to student procedure 3 in Part One before providing materials for Part Two. From the first activity, students should have the understanding that Kepler’s First Law states that planetary orbits are oval shaped. Students probably will not use the term elliptical. You may introduce the term ellipse when you think the time is right, though it is mentioned in the title of Part Two.
10. Once you have checked the groups’ work for Part One, provide the materials for Part Two. Provide assistance as necessary. After students have drawn the ellipse using the string method, make sure they continue to label the “focus” at the point where the pins were. At this point you may need to provide assistance in helping students understand the terms listed in the student procedure items 11-16.
11. Hold a discussion about the words *perihelion* and *aphelion*. Based on the definitions for these terms in the student activity (student procedures 11 and 12), ask students what they think the suffix *helion* stands for (sun, from the Greek helios). Continue the conversation by telling students about the terms *perigee* and *apogee*. Tell them that these terms refer to the orbit of the Earth and its moon. Based on what they have learned from the activity, ask them to define *perigee* and *apogee*. (Perigee is the closest point the moon is to the Earth in its orbit; apogee is the farthest point the moon is to the Earth in its orbit.)
12. As the students continue working on calculating the eccentricity of their ellipse, circulate around the room checking to see that they labeled the semi-major axis (a) and the distance from the center of the ellipse to the focus (c).
13. When calculating eccentricity for the planets, instruct students to round each answer to the nearest thousandth. Once students have found the eccentricity of each of the planet’s orbits, have them complete the questions that follow. Suggested answers are below.
 - a) Which planetary orbit is most eccentric? (Pluto, 0.249). What does this mean? (Its orbit is the least round.)
 - b) Which planetary orbit is closest to being a circle? (Venus, 0.007)
 - c) Which two orbits have the closest eccentricity? (Jupiter 0.048 and Uranus 0.049)
 - d) What other planet has an orbital eccentricity most similar to the Earth’s? (Neptune, 0.009)

Alternate Strategy Tip

For the Student Activity, “Round and Round,” (Part Three), use the student spreadsheet [Calculating Orbital Eccentricity of the Planets](#) as a technology application for solving the eccentricity of the orbits of the planets. The spreadsheet may be printed out for each student.

Planet	Eccentricity
Mercury	0.207
Venus	0.007
Earth	0.017
Mars	0.093
Jupiter	0.048
Saturn	0.056
Uranus	0.047
Neptune	0.009
Pluto	0.249



14. Part Four of “Round and Round” involves having the students look at a diagram of the planetary orbits. The point of this is for students to realize that although the orbits are elliptical, the eccentricity truly is small. Point out how difficult it must have been for Kepler to determine that the orbits are ellipses based on information available at the time. Conclude this series of activities by asking the students to write down Kepler’s First Law of Planetary Motion in their own words.

PROCEDURE (Part Two):

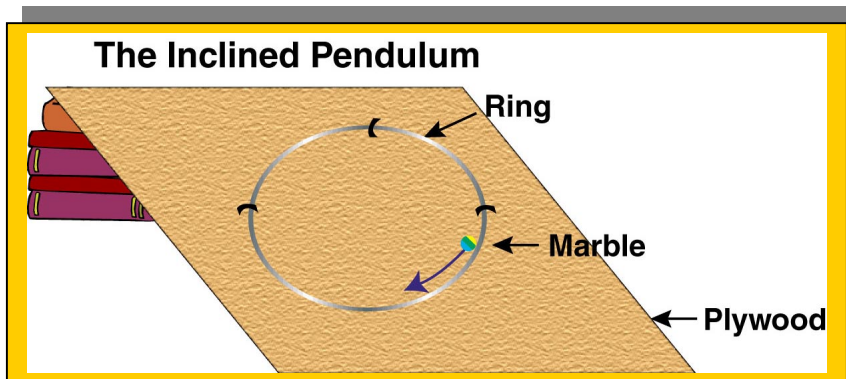
“Sweepstakes”

1. Distribute the Student Activity, “Sweepstakes!” to each student. Make Kepler’s Second Law, Animation, available. Instruct individuals to describe the speed of the planet at different locations. Students should indicate that the planet appears to be going faster when it is closer to the focus (sun).
2. Explain to students that the diagram on the bottom of the student activity shows a planet’s orbit around the sun. Ask students what they notice about the time it takes to go from A to B versus the time it takes to go from C to D. Tell students that for the second procedure they should find the area of the two shaded areas using the same method as in Part One. (They should be very close to equal.) Once they have completed this, ask students to complete the last three questions. They should be able to fill in the blanks, “Planets sweep out equal *areas* in equal *time*.” If students ask what is meant by “sweep,” explain that this refers to an orbital starting point, an orbital ending point with imaginary lines back to the focus (sun).

PROCEDURE (Part Three):

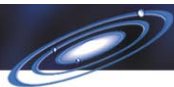
“The Inclined Pendulum”

1. There is some advance preparation for this activity. The teacher should obtain enough plywood and metal rings for each student group. The rings can be mounted on the plywood with a couple of industrial staples or heavy-duty tape.
2. Before distributing the student activity, demonstrate how the inclined pendulum can be used to model a decrease in gravity. Set the apparatus on a book and demonstrate how to roll the marble. Place the marble on the inside of the ring and release. Students should practice counting the number of times the marble swings in 10 seconds. Repeat this several times so the students determine the best way to count swings. One way might be to count the number of times it passes by a mark on the wood by the bottom of the ring. Emphasize how it is important for the students to release the marble from the same point for each trial. Explain to students that after completing three trials for one book, they should add a second book under the apparatus and repeat. Tell students that this simulates an increase in gravity. You can view the activity online in the Genesis Webcast titled “Kids Get Down With Gravity” at <http://www.jpl.nasa.gov/webcast/genesis.html>
3. Distribute the Student Activity, “The Inclined Pendulum.” Students should follow the procedure, fill in the data table, and make a graph showing their results.
4. Suggested answers for student procedures 8-9 are below.



Alternate Strategy Tip

This activity can be completed as a class demonstration with the students collecting the data from one apparatus.



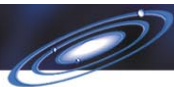
- Based on your results, how does the amount of gravity affect the velocity of the marble? (Students may state that the more books that are used, the more swings the marble makes in 10 seconds. Therefore, an increase in the gravity results in faster marbles.)
 - In what ways does this compare with planets orbiting the sun? (According to Newton's Law of Gravitation, masses at greater separations have less gravitational force than those closer together. Therefore, planets that are farther from the sun have less gravity than those that are closer.)
5. Procedures 10 and 11 on the student activity refer to the table of mean orbital velocities. Students should make the connection that more distant planets travel around the sun more slowly than those closer to the sun. Suggested answers for procedures 10 and 11 are below.
- Based on the mean orbital velocity and the mean distance from the sun, describe the relationship between the distance from the sun and the orbital velocity. (Students should suggest that based on this data table, the farther the planet is from the sun, the slower its orbital velocity.)
 - Describe Kepler's Third Law of Planetary Motion in your own words. (Answers will vary, but students should suggest that the more distance from the planet to the sun, the slower the planet moves.)
6. Once students have completed each of the activities, distribute the Student Text, "[L1 or Bust!](#)" to each student. This text reviews the concepts from the activities in this teacher guide and challenges students to interpret the Genesis launch trajectory graphic. Answers for these questions are below.
- At what distance did the Genesis spacecraft cross the moon's orbit? (Just under 0.5 million kilometers.)
 - How long did it take for the Genesis spacecraft to arrive at L1? (2.7 months)
 - How many orbits did the Genesis spacecraft make around L1? (5)
 - What is the approximate diameter of each of these orbits? (1.5 million kilometers)
 - How many months does each orbit take? (29.3 months divided by 5 orbits = 5.86 months)
 - Describe the Genesis spacecraft's trip back to the Earth. (Answers will vary. Some students may suggest that the spacecraft travels back to the Earth, just beyond the moon's orbit, and then goes to L2 to reposition itself for a daylight reentry.)
 - Why will the Genesis spacecraft travel around L2? (It does this so that it can achieve a daylight reentry. You may want to add that this is because of the helicopter capture.)
 - What year will the Genesis spacecraft return to Earth? (2004)
 - How many years will the Genesis spacecraft spend in space? (37.3 months divided by 12 months per year = 3.11 years)
 - Why is the sun not shown in this graphic? (Students may suggest that the sun does not fit into this scale. It would be another 92 million miles away from the L1 point.)
 - Write a paragraph describing the trajectory of the Genesis spacecraft. (Answers will vary, but students should indicate the outward leg, the five halo orbits, and the return and recovery aspects of the trajectory.)
7. Once the students have completed all of the activities and texts on Kepler's laws, ask them to take out their journals and look at some of the questions they wrote down at the beginning of this unit. Ask them to write answers based on information they learned in this unit. Next, ask students to record a summary of what they learned in their journals. Finally, ask them to write additional questions they have as a result of activities in this unit. Hold a class discussion on how they might go about finding answers to questions that they still have about planets' orbits.

Teaching Tip

Students may not know the definition of an astronomical unit (AU). Encourage interested students to use the Genesis glossary to find the definition.

Teaching Tip

One teacher who used this activity recommended that high school students could use Kepler's Third Law to calculate orbital periods of the planets. See procedures 12 and 13 on the student activity.



TEACHER RESOURCES

URLs

<http://csep10.phys.utk.edu/astr161/lect/history/kepler.html>

Kepler's laws of planetary motion

<http://csep10.phys.utk.edu/astr161/lect/solarsys/revolution.html>

Revolution and rotation of the planets

http://map.gsfc.nasa.gov/m_mm/ob_techorbit1.html

Goddard Space Flight Center MAP education outreach program re: LaGrange points

http://solarsystem.nasa.gov/features/planets/planet_profiles.html

Profiles of the planets

<http://www.kepler.arc.nasa.gov/johannes.html>

Kepler biography

<http://www.nasaexplores.com/lessons/01-079/>

What is orbit?